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Variability in the Duration of Rains and Other Elements of the Rain Course

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ABSTRACT

Rains of varying intensity and duration have different effects on the water balance of territories and economic indicators of regional development. The paper examines the features of changes in time and in various physical and geographical conditions of the duration of rains and the position of the maximum intensity during rain. It is shown that in mountainous areas there is more precipitation, both in quantity and frequency.The research used methods of mathematical statistics and graphical analysis.In general, for all four meteorological stations, which were studied, a similar distribution of the probability of occurrence of rains with a given duration is characteristic. Rains lasting more than 400-500 minutes occur in less than 10% of all meteorological stations. For rains lasting less than 300 minutes, there is a difference in the probability of occurrence of 5-10% between meteorological stations. Some limits of air humidity, air temperature and soil surface at which rain was not observed are determined, what is important when forecasting. Analysis of the influence of meteorological parameters on the duration of rains and the position of the maximum intensity during rain shows that at an average relative humidity of less than 45-50 percent there was practically no rain, and at a minimum relative humidity of less 30% as well. Air temperature (average, maximum and minimum) of 20-25 °C is critical, above which rains lasting more than 400-500 minutes did not occur. The longest rains are observed at low average daily air temperatures, less than 10 °C. At a minimum soil temperature of 20 °C and above, rains are practically not observed (4 cases out of 989). At an absolute maximum soil surface temperature of more than 50 °C, prolonged rains of more than 500 minutes are also practically not observed.

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Introduction

The rain course is usually a change in rain intensity over time. The elements of the rain course include such characteristics as the duration of rainfall and the position of the maximum intensity during the rain [1].

Duration of Rainfall

The duration of rainfall is one of the frequently used characteristics [2-7]. Rains of varying intensity and duration have different effects on the water balance of territories and economic indicators of regional development. Information about the characteristics of precipitation is important for the economic use of any territory [8-12]. Based on this information, drainage networks are formed, anti-erosion measures are designed, irrigation regimes are determined, etc. They are also widely used to predict floods, landslides, mudflows etc. [13-15].

Thus, according to, the main criterion for the formation of mudflows in the Carpathians is the amount and intensity of precipitation in the form of rain; in the event of rainfall of 20 mm or more in 12 hours or less, a warning is given about the possibility of a mudflow [16]. The duration of rainfall is an additional condition in the criteria for dividing the intensity of the manifestation of mudflow hazard, since it characterizes, in addition to the rains themselves, the degree of moisture in the catchment area (indirectly). Long-term rains contribute to the moistening of the soil layer and cause longer mudflows than short-term rains [17]. When predicting landslides, it is also recommended to use the duration of rainfall as a criterion for occurrence [18]. Modern approaches to urban development and beyond also require consideration of the entire spectrum of rainfall: from short to the longest [19,20]. Modern climate changes, which are widely discussed in publications by many authors, show that expected rainfall activity may pose a significant threat to economic activity in many areas [21-28].

Visual observations of the duration of atmospheric phenomena, including the duration of precipitation, were organized in the USSR since 1936 at all meteorological stations. Information on the duration of rain can also be obtained from observations using pluviographs, VOA-1M, etc. (at a limited number of meteorological stations).

A.N. Lebedev, analyzing visual observations of the duration of precipitation and observation data from pluviographs, found that the data from the pluviograph give an underestimated duration of precipitation, since the device has insufficient sensitivity to small precipitation, so, in the case of frequent small and drizzling precipitation, the portion of the unaccounted duration of precipitation can be 40-50% [29]. However, it is small and drizzling precipitation that create unfavorable conditions during the construction and operation of some facilities. The aim of the research was to examine the change in the duration of precipitation in different physical and geographical conditions and over time, and to determine the influence of meteorological elements on the duration of rain.

Position of Maximum Intensity During Rain

The characteristics of rainfall patterns across Ukraine have been studied before. For example, studies based on observations before 1935 allowed them to identify 6 types of rain based on the characteristics of rainfall intensity: type 1 – maximum intensity is observed at the beginning of the rain, type 2 – maximum intensity is in the first third of the rain, type 3 – maximum intensity is observed in the middle of the rain, type 4 – maximum intensity moves to the last third of the rain, type 5 – approximately uniform rainfall is observed, type 6 – two maxima are observed during the rain period. According to the authors of, types 1 and 6 of rain are most common [30]. The studies were then confirmed by L.K. Grigorieva for the observation period of 1951-1954 (77 showers) [30,31].

L.D. Mikhalskaya notes that showers and torrential rains are characterized by great variability in time, the maximum intensity most often occurs in the first half of the rain (in the first 30 minutes) [32]. D. Stephenson also believes that the greatest intensity of a shower is observed at its beginning, however, for some areas a shift to a later time is also possible, the magnitude of the shift depends on the preceding wetting [33]. The fundamental importance of this issue is well reflected in the work of D. Stephenson: a shower reaching a maximum at the initial stage can give a smaller flood water discharge than a shower reaching a maximum at a later moment [33]. When designing, the duration of the calculated shower should be equal to the time of runoff concentration for the catchment area with a uniform shower and maximum runoff of any given repeatability. Our studies show that the course of rain significantly affects the formation of runoff and soil erosion on slopes [34]. During showers of significant intensity with a maximum intensity at the beginning of the shower, the soil moisture is lower, the soil density is higher, and the particle fragmentation is higher than in less intense showers. The greatest sediment runoff is observed in the range of the position of the maximum precipitation intensity from 0.1 to 0.3 relative to the total duration of the rain. However, some scientists believe that the maximum intensity of rainfall tends to its middle, so according to N.K. Mirotvorskaya the hypothesis about the normality of the distribution of rainfall intensity is true. When modeling rains by sprinkling V.A. Belolipsky et al. assumed that the rain intensity obeys the law of normal distribution [35,36].

The selection of distribution functions during in the study precipitation is still carried out today since the issue concerns many aspects of human economic activity [37-39].

The aim of the research was to examine changes in the duration of precipitation in different physical and geographical conditions and over time, to determine the influence of meteorological elements such as air temperature, soil surface temperature, average and maximum relative humidity, etc. on the duration of rain.

The conducted studies show that, despite repeated attempts to study the features of the distribution of rain characteristics, different approaches to their research and generalizations, there are still many obstacles to reliable forecasting of these elements of rain due to their significant variability, which hinders adequate management of measures to prevent natural consequences from rains.

Materials and Methods

To study the characteristics of the rain course, the observation materials of the State Hydrometeorological Service of Ukraine were used at four meteorological stations: Kyiv, Kovel, Kamenka-Buzka and Yaremche. The locations of these stations are schematically shown in Figure 1. The Kovel meteorological station is located in the mixed forest zone on the Poliesie lowland. The Kyiv and Kamenka-Buzka meteorological stations belong to the forest-steppe zone of Ukraine, and Kamenka-Buzka is located in the western part of this zone on the Dnieper Upland, which is characterized by increased humidity. The Kyiv meteorological station is located on the Dnieper Lowland. The Yaremche meteorological station is located in the mountainous area of the Ukrainian part of the Carpathians.

The series of observations of the course of rains at the studied meteorological stations are not of the same duration, there are breaks in observations in the series (Table 1, Figure 2), which is mainly due to the breakdown of pluviographs. More detailed information about the features of observations of the course of rains was described in [40]. The longest series of rains observations at the meteorological stations under study is available at the Kyiv meteorological station, with interruptions in observations over a period of almost 100 years (Table 1). Rain records were made using a Gelman pluviograph with a receiving area of 500 cm2. During this time, the approach to the analysis of recorder tapes (pluviographs) and the selection of pluviograph records for analysis changed. Thus, until 1935, torrential rains were selected for analysis and publication according to the standards of E. Berg, where torrential rains were understood as rains during which, for a given period of time, the rain intensity did not fall below certain intensity values [41,42]. Later the tapes were processed according to the method presented in the Manual for Hydrometeorological Stations and Posts, and the collection published materials on rains, the amount of precipitation for which was 10 mm or more [43-46]. The priority in publishing materials on observations of the course of rains using pluviographs with a precipitation amount of 10 mm or more has been preserved to this day [47]. It is believed that it is precipitation of 10 mm or more that forms floods on rivers.

Figure 1: Location of Meteorological Stations where Research is being Conducted (●)

Source: the map base is taken from the Internet (physical_maps_of_ukraine.jpeg)

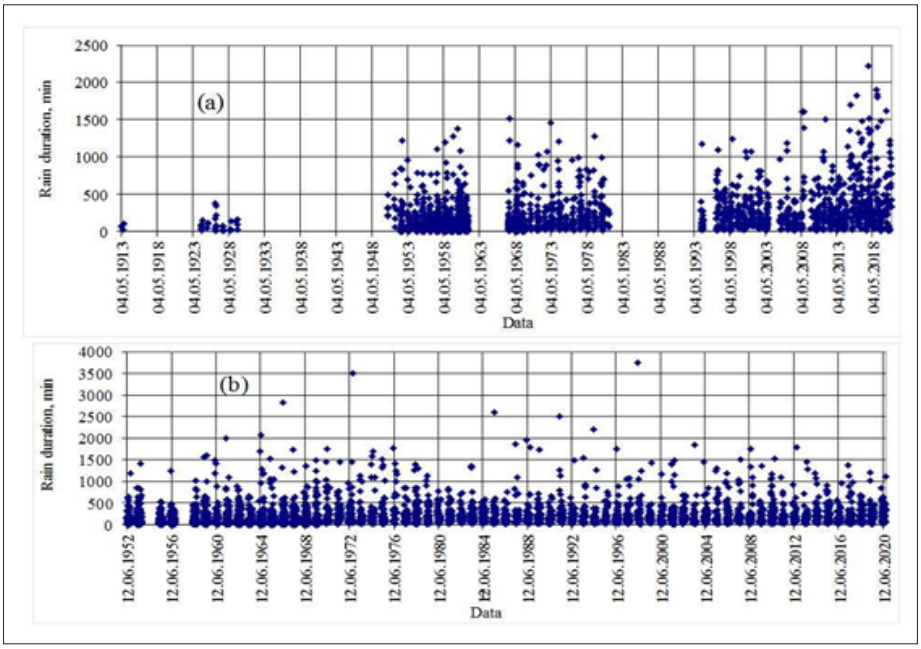

Figure 2: Change in the Duration of Rains over time at Meteorological Stations (a) Kyiv and (b) Yaremche

The main research methods were statistical analysis with elements of probability theory and graphical data analysis.

Until the 1970s, decoding materials from pluviograph tapes with all recorded liquid precipitation were placed in TM-14 tables; later, only materials with precipitation amounts of 2.5 mm or more were placed there. Since 1984, observation materials from pluviographs for rains with precipitation amounts of 2.5 mm or more have been placed in TMS-1 summary meteorological tables. In addition, at most meteorological stations, rainfall is recorded using pluviographs from May to September (this also applies to the Kovel, Kamenka-Buzka, and Yaremche meteorological stations). However, at some meteorological stations, including the Kyiv meteorological station, in recent years (from 2009 to 2013), rains observations using pluviographs were conducted from April to November, and since 2014, they have been conducted almost monthly, since in recent years, cases of liquid precipitation in the winter have become more frequent.

The series of observations of atmospheric precipitation are not uniform according to several criteria - the time of observations and the boundary conditions of selection (2.5 mm and more).

It should be noted that at the Yaremche meteorological station, which is located in a mountainous area (Carpathians), the amount of precipitation per year is greater (Figure 3) and the total number of recorded rains is also greater than at other studied meteorological stations (Table 1). The significant roughness of the surface in mountainous areas creates favorable conditions for the condensation of water vapor and precipitation.

Data for the Kyiv meteorological station from 1913 to 1929. taken from the publication, and for 1950-51 and 1957 from, where selected rains are placed, in the first case, rains related to the concept of downpour according to Berg, in the second case - rains with the amount of precipitation greater than or equal to 10 mm [41-43]. The concept of "downpour" is understood, as a rule, not as the amount of precipitation, but as how it fell, the more intense - the more atmospheric precipitation falls under the concept of downpour.

Observations of the course of rainfall in our country were carried out for almost a 100-year period using rain recorders: ombrographs, later Gelman pluviographs, P2 (recording of changes in water level on a chart form), a modern electronic VOA-1M meter (weight mechanism, weighing water that enters the meter after 2 g, which corresponds to 0.1 mm of atmospheric precipitation) [44-46,48]. From the pluviograph tapes, readings were taken either at turning points (before 1970), or at 10-minute intervals, and even later, combining intervals with a small difference in precipitation intensity values was allowed [46].

Research shows that there is very little rainfall data with a resolution of 1 minute or close to it worldwide [49]. Such a time resolution of rainfall research is usually characteristic of data for the last 20-30 years. In most cases, precipitation data are analyzed for a year, month, season, and, less often, a day [50,51].

The following indicators were used in this study from the characteristics of rainfall: 1) duration of rainfall; 2) position of the maximum intensity during rainfall, if there were two or more identical maximum values, the first maximum from the beginning of rainfall was selected; 3) number of peaks (maxima) during rainfall, all peaks in the rainfall intensity over time given in the decoding of the pluviogram were selected, which were higher than the closely located rainfall intensity values. Provision (P) of rainfall characteristics was calculated using the formula:

$$P = 100\,m/n+1$$

where m is the number in descending order of the value of the rain characteristic; n is the total number of rain characteristic values under consideration.

Table 1: Characteristics of Observation Periods for the Studied Meteorological Stations

Characteristics	Absolute height above sea level, m	Number of observed rains	Years of observations of the course of rains using a pluviograph	Range of change in precipitation amount per rain, mm	Range of change in rainfall duration, min
Kyiv	177	2261	1913, 1924-29; 1950-1961; 1967-1981; 1994; 1996-2003; 2005-2020	0,1 – 76,7	1 – 2218
Kovel	173	1328	1952-60; 1966-99	0,1 - 90,5	3 - 2046
Kamenka-Bugskaya	212	1972	1963-85; 1988- 2018	0,4 – 98,5	3 - 2505
Yaremche	531	4374	1952-53; 1955-56; 1958-2020	0,1 - 166,1	1 - 3760

In addition to observation materials from pluviographs, materials from daily observations of the course of meteorological variables at the Kyiv meteorological station at a height of 2 m from the earth's surface were used for all meteorological elements except for the soil surface temperature in order to determine the conditions for rainfall. Here, the data from 1977 to 2020 (989 rains) were used; earlier materials were not used, since there was a different form of recording the generalized values of meteorological elements. Also, since the climate changes that have occurred in recent decades show an increase in air temperatures in the autumn-winter and winter-spring periods, since 2012-13 there are records of the course of rains in the winter-spring period (october-april), when precipitation fell in liquid form. Materials on meteorological elements on the date of the onset of rainfall in these periods sometimes include negative air and soil surface temperatures, since they are taken as average daily temperatures, and not at the minute the rain began. The number of cases with negative average daily air temperature is 33 times, negative absolute maximum air temperature is 17 times, negative absolute minimum air temperature is 50 times. The number of cases with negative average daily soil surface temperature is 30 times and equal to zero - 25 times, negative absolute maximum soil surface temperature is 10 times and equal to zero - 26 times, negative absolute minimum soil surface temperature is 60 times and equal to zero - 32 times. However, the atmospheric precipitation recorded at this time fell in liquid form. In it is emphasized that according to the Kyiv meteorological station in the winter months, the percentage of liquid precipitation on average for the observation period of 1891-1964 is for November - 54% of the total precipitation for the month, for December - 22%, January - 12%, February - 10% and March - 25% [52].

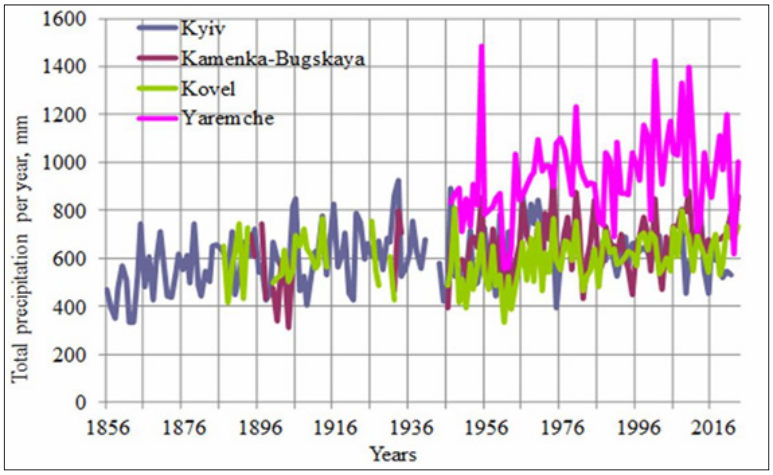

Figure 3: Change in the Amount of Precipitation per year at the Meteorological Stations Kyiv, Kamenka-Bugskaya, Kovel and Yaremche over time

Results

The series of observations of rain characteristics show significant variability (Table 2) and rare recurrence of extreme values (Figure 4).

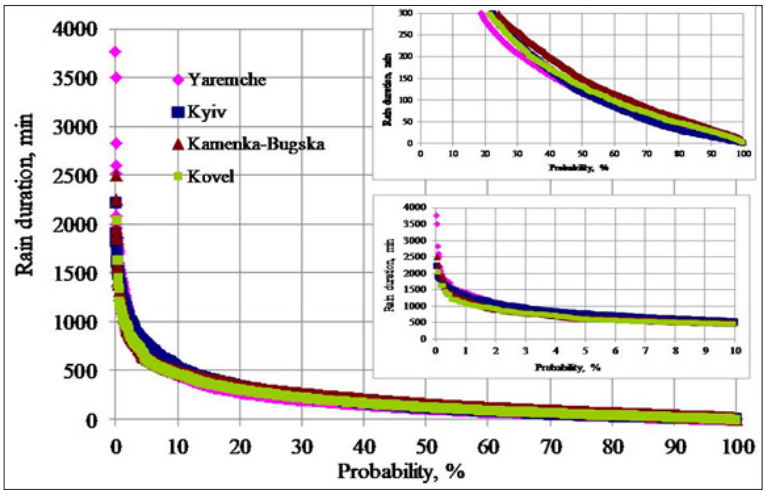

Figure 4: Probability of Duration of Rains at a Number of Meteorological Stations

Table 2: Statistical Analysis of the Studied Rain Characteristics

Characteristics of rain		Kyiv	Kovel	Kamenka-Bugskaya	Yaremche
Duration of rainfall, min	Average	212,9	203,3	222,5	202,3
	Dispersion	70200,0	49157,6	55287,5	72515,8
	Asymmetry	2,6	2,6	3,0	4,0
	Excess	8,8	10,3	15,1	25,5
Position of maximum rainfall intensity, min	Average	104,0	84,4	88,3	89,7
	Dispersion	26111,2	19864,5	18691,2	24416,7
	Asymmetry	3,5	3,4	4,5	5,1
	Excess	18,5	15,2	40,4	39,9
Number of peaks during rainfall	Average	2,4	2,3	2,0	2,9
	Dispersion	4,0	2,6	2,6	9,3
	Asymmetry	3,4	1,9	2,4	5,2
	Excess	20,1	4,7	9,6	44,6

Frequency analysis of the studied values also showed a high number of short rains, significantly prevailing over long rains, which is typical for all the studied meteorological stations (Figure 5-6). The values of the interval length and the number of rains that fall into the first interval are affected by the height of the catchment area (Figure 7). Research over 2 years shows that orographic factors contribute to longer precipitation duration and higher precipitation frequency, but do not affect their intensity [53].

In the calculations for constructing histograms (Table 3, Fig. 5-6), the interval length was determined using the Sturges formula [54]:

$$h = \frac{X_{max} - X_{min}}{1 + 3{,}322 \lg(n)}$$

where h is the length of the interval, X_{max}, X_{min} are respectively the maximum and minimum values of the studied quantity, n is the number of members of the series.

Table 3: Some Characteristics of Frequency Analysis of Rain Duration

Characteristics	Weather station			
	Kyiv	Kovel	Kamenka-Bugskaya	Yaremche
Length of the interval,, min	183	180	209	287
Number of rains with a duration not exceeding the length of the interval (number of occurrences in the first interval)	1413	816	1211	3514

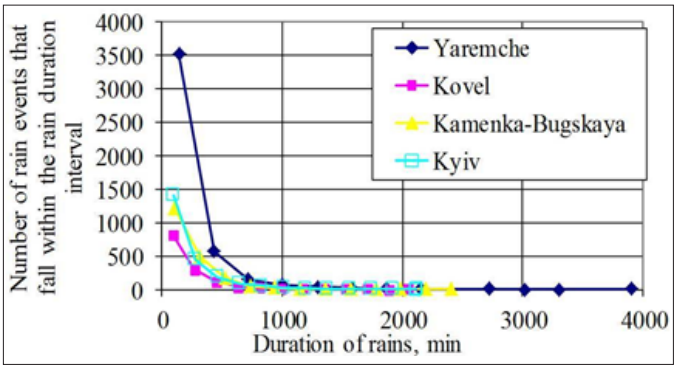

Figure 5: Histogram of the Frequency of Occurrence of Rains with a Given Duration

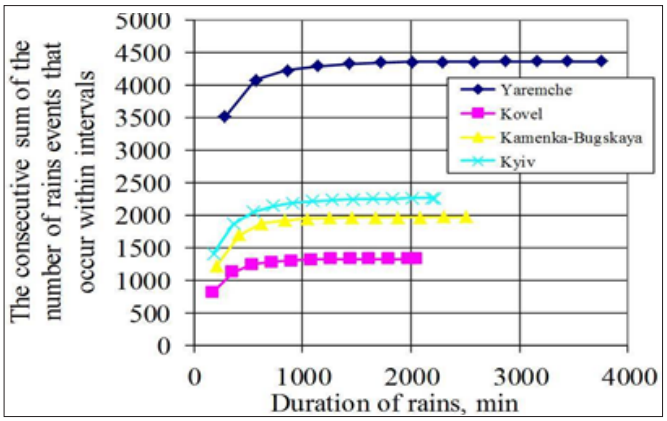

Figure 6: Cumulative Curve of the Number of Rains Events in a Given Rains Duration Interval

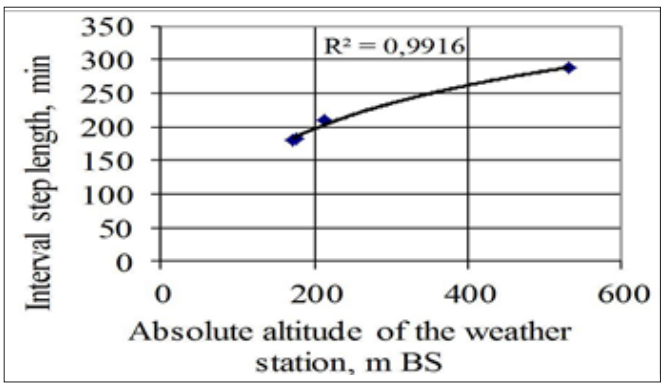

Figure 7: Dependence of the Interval step Length on the Terrain Height

Despite the diversity of physical and geographical conditions and the time of rain formation, the curves of precipitation duration probability are similar in general for the entire set of observations at meteorological stations (Figure 4). Rains lasting more than 400-500 minutes occur in less than 10% of all meteorological stations. For rains lasting less than 300 minutes, there is a difference in the probability of occurrence between meteorological stations of 5-10% (Figure 4). Rains lasting less than 60 minutes account for 20-30% of the total number of samples. Moreover, the Kyiv weather station is characterized by 30-32% of all rains, and Kamenka-Buzka 20%, the Kovel and Yaremche weather stations occupy intermediate values between them (Kovel - 25%, Yaremche - 28-29%).

Analysis of the influence of duration of rains on the number of peaks (intensity maxima) during their course shows that, in general, the number of peaks can be small or large for different durations of rains, but the longest rains are still characterized by a larger number of peaks (Figure 8). Rains with a number of peaks greater than 5 during rains with a duration of up to 1 hour do not occur. The longest rains are typical for the Yaremche meteorological station (up to 3760 min) and the largest number of peaks during rains is also noted at this meteorological station (up to 46). It is considered that rains with one peak are single-cell, and with several - multi-cell according to the conditions of rain origination from many cells [55].

The graphs of the relationship between the duration of rain and the position of the maximum rain intensity are presented in absolute values, since in the practice of designing various water drainage structures, data are used in minutes, and not in relative units (Figure 9), therefore the field of points is distributed mainly in the lower half of the coordinate system, since the position of the maximum intensity cannot be greater than the duration of the rain itself [8,9]. The field of maximum rainfall location points during a rain event is distributed within a certain range of values that does not exceed the duration of the rain.

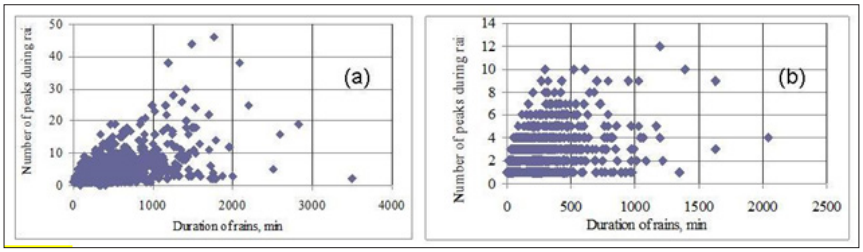

Figure 8: Duration of Rains and the Number of Peaks During their Course (a) - According to the Yaremche Meteorological Station, (b) - According to the Kovel Meteorological Station

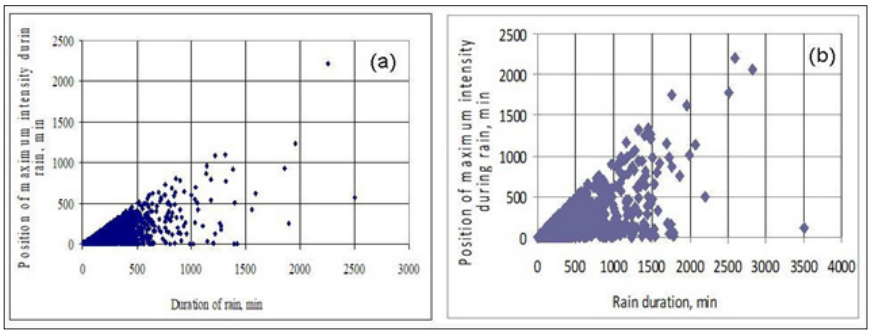

Figure 9: Relationship between Duration of Rain and Position of Maximum Precipitation Intensity During Rain, Min (a) - Kamenka - Bugskaya, (b) - Yaremche

Figures 8-9 demonstrate the predominance of smaller rain grains in the structure of shorter rains compared to longer rains.

Research into the relationships between annual and monthly precipitation amounts with air temperature, humidity and other meteorological elements has been and is being conducted on an ongoing basis [56]. This indicates the importance and versatility of such relationships. Research into the relationships between rain characteristics and meteorological elements is limited by the availability of detailed studies [34]. Often, the relationship between rain characteristics and meteorological elements has been studied at the altitude of cloud formation [57]. However, many studies show a link between increased precipitation and rising temperatures in the context of climate change [58].

Analysis of rain and meteorological observation materials at the Kyiv meteorological station showed that during the observation period under consideration, there was practically no rain at an average relative humidity of less than 45-50 percent (Figure 10), and at a minimum relative humidity of 30% and below as well. Air temperature (average, maximum and minimum) of 20-25 °C is critical; above this temperature, rainfalls lasting more than 400-500 minutes did not occur. The longest rainfalls are observed mainly at low average daily air temperatures, less than 10 °C (Figure 11). It should be emphasized that rainfall itself in the warm part of the year contributes to a decrease in air and soil surface temperature, since the temperature of the precipitation itself is close to zero °C [34]. And in the cold part of the year, apparently, liquid precipitation is caused by warm air masses moving from southern latitudes. I would like to emphasize that the characteristics of meteorological elements for the day at the time of the onset of rain were used.

Similar trends are also found for the dependencies of the position of the maximum intensity of rainfall, etc. (Figure 12).

At a minimum soil temperature of 20 °C and above, rain is practically not observed (4 cases out of 989) (Figure 13). At an absolute maximum soil surface temperature of more than 50 °C, prolonged rains of more than 500 minutes are also practically not observed (Figure 14).

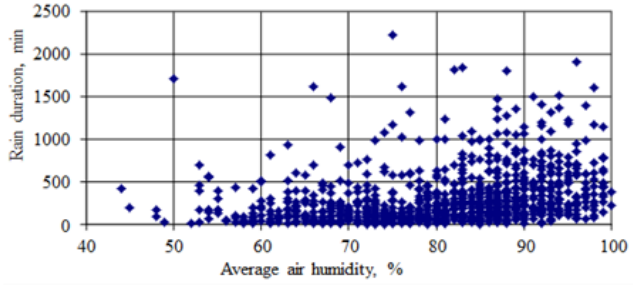

Figure 10: Relationship between the Duration of Rainfall and Relative with Average air Humidity at the time of Rainfall According to the Kyiv Weather Station

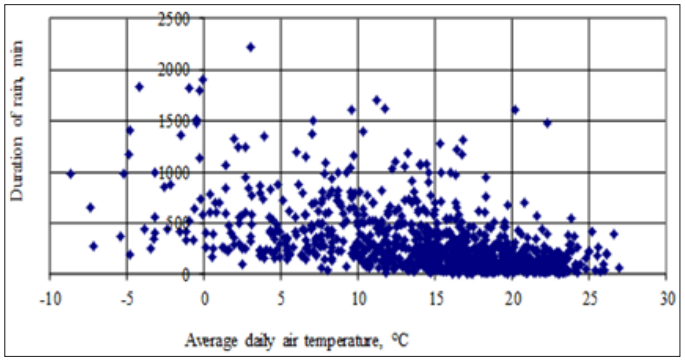

Figure 11: The Relationship between the Duration of Rainfall and the Average Daily air Temperature at the time of Rainfall According to the Kyiv Weather Station

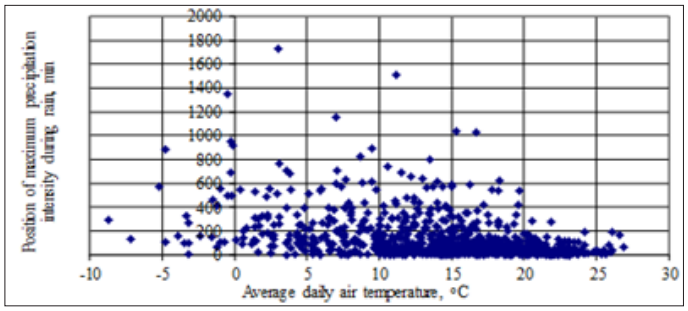

Figure 12: Relationship between the Position of the Maximum Precipitation Intensity During Rain and the Average Daily Air Temperature at the time of Rainfall at the Kyiv Weather Station

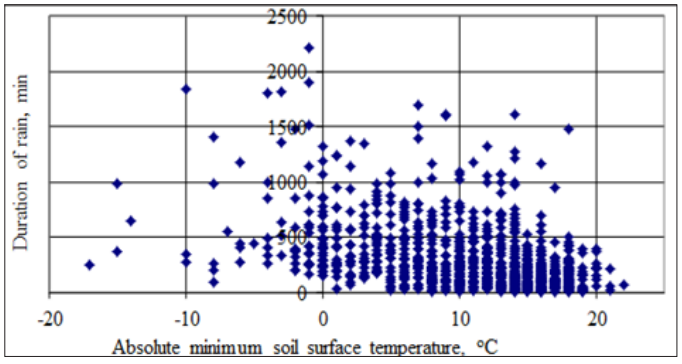

Figure 13: Relationship between the Duration of Rainfall and the Absolute Minimum Soil Surface Temperature at the time of Rainfall According to the Kyiv Weather Station

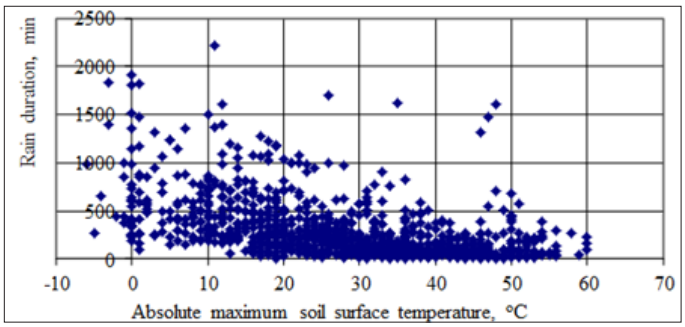

Figure 14: Relationship between the Duration of Rainfall and the Absolute Maximum of Soil Surface Temperature at the time of Rainfall at the Kyiv Meteorological Station

The dependencies presented in Fig. 10-14 allow us to determine meteorological conditions under which the occurrence of rains themselves is unlikely and the occurrence of long or short rains is possible, which will allow us to track similar conditions during forecasting and provide more adequate forecasts. We are not aware of any studies based on such data.

Conclusions

The conducted studies show significant variability in the characteristics of the Dodge movement The conducted studies show that for flat areas (Kovel, Kamenka-Bugska, Kyiv), the number of rainfalls and the distribution features of their parameters are more similar to each other compared to mountainous areas (Yaremche). The west (Kovel, Kamenka-Bugska, Yaremche) is characterized by greater moisture in the territory and the number of rains here is also greater.

Frequency analysis of the studied values showed a high number of short rains, significantly prevailing over long rains, which is typical for all the studied meteorological stations. The values of the interval length and the number of rains that fall into the first interval are affected by the height of the catchment area.

Despite the diversity of physical and geographical conditions and the time of rain formation, the curves of the probability of precipitation duration are similar in general for the entire set of observations at meteorological stations. Rains lasting more than 400-500 minutes occur in less than 10% of all meteorological stations. For rains lasting less than 300 minutes, there is a difference in the probability of occurrence of 5-10% between meteorological stations. Analysis of the influence of meteorological parameters on the duration of rains and the position of the maximum intensity during rain shows that at an average relative humidity of less than 45-50 percent there was practically no rain, and at a minimum relative humidity of 30% as well. Air temperature (average, maximum and minimum) of 20-25 °C is critical, above which rains lasting more than 400-500 minutes did not occur. The longest rains are observed at low average daily air temperatures, less than 10 °C. At a minimum soil temperature of 20 °C and above, rains are practically not observed (4 cases out of 989). At an absolute maximum soil surface temperature of more than 50 °C, prolonged rains of more than 500 minutes are also practically not observed. The presented results of the distribution of the relationships of meteorological elements with the characteristics of the rain course during forecasting will allow tracking similar conditions and provide more adequate forecasts.

A study of the course of rain over time in the existing period of rain observations shows no tendency for the duration of rain to increase.

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Data Availability Statement
The data from the Hydrometeorological Service of Ukraine, which are available in the state industry archive of Ukraine, were used. Partially, the materials on observations by pluviographs were published in Meteorological Monthly since 1961 with the amount of precipitation more than 10 mm, these data are available in state libraries.

Conflicts of Interest
There is no conflict of interest

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